COMMENTS ON NON-SUPERSYMMETRIC TYPE I VACUA

K. Förger
Centre de Physique Théorique, École Polytechnique
91128 Palaiseau Cedex, France

Abstract We review open descendants of non-supersymmetric type IIB asymmetric orbifolds with zero cosmological constant. We find that supersymmetry remains unbroken on the branes at all mass levels, whereas it is broken in the bulk.

Orbifold compactifications which break supersymmetry while keeping the cosmological constant at one loop, two loop and possibly up to all orders in perturbation theory to zero, have recently attracted much attention [1]. A modification of the initial four dimensional model led to a model in five dimensions, which allows for a heterotic dual, thereby giving rise to non-vanishing non-perturbative corrections to the cosmological constant [2]. In the following we will focus on the main results of the construction of open descendants for Harvey's model, which has been worked out in detail in [3] and using a different formalism in [4]. For a more complete list of references and more details we refer the reader to [3].

Parent closed string theory: To begin with, we consider type II theory in $d = 5$ compactified on the lattice $\Gamma[\mathrm{SU}(2)]^4 \oplus \Gamma_{1,1}(R)$. The radius of $\Gamma[\mathrm{SU}(2)]$ is the self-dual radius $R = \sqrt{\alpha'}$, whereas the radius of the circle of the fifth coordinate is left arbitrary. Then we start modding out this theory by the asymmetric orbifold, which is generated by the following two elements [2]:

$$
\begin{aligned}
f &= \Big[(-1^4, 1\,;\, 1^5)\,,\, (0^4, v_{\mathrm{L}}\,;\, \delta^4, v_{\mathrm{R}})\,,\, (-)^{F_{\mathrm{R}}}\Big]\,, \\
g &= \Big[(1^5\,;\, -1^4, 1)\,,\, (\delta^4, v_{\mathrm{R}}\,;\, 0^4, v_{\mathrm{L}})\,,\, (-)^{F_{\mathrm{L}}}\Big]\,,
\end{aligned}
$$

*CPHT-PC736.0999

where δ is a shift by $R/2$ and $v_{\rm L/R}$ shifts the fifth coordinate by

$$X_{\rm L/R} \to X_{\rm L/R} \pm \frac{1}{2}\Big(\frac{\alpha'}{R} \pm R\Big) \ ,$$

which corresponds to a symmetric shift in momentum and winding modes of $\Gamma_{1,1}$, thereby balancing the level matching condition. The action of $(-1)^{F_{\rm L/R}}$ breaks the space-time supersymmetry of the L/R movers and therefore the combined action of the orbifold generators f and g will break supersymmetry completely. Note that the above orbifold is non-Abelian from the space group point of view, whereas the point group, which is obtained by modding out the space group by pure translations, generated by f^2 and g^2, is an Abelian asymmetric $Z_2 \times Z_2$ orbifold. This transition from the space group to the point group modifies the lattice $\Gamma[{\rm SU}(2)]^4$ into the lattice $\Gamma[{\rm SO}(8)]$, which includes a non-trivial NS-NS antisymmetric tensor B_{ab} of rank 2 in the internal lattice. This fact already hints at a reduction of the resulting gauge group of the open string spectrum [5, 6, 7]. The above orbifold can be seen as a freely acting orbifold of T^4/Z_2 by f.

Acting with $Z_2 \times Z_2$ on the torus partition function, we get the following massless contributions

$$\begin{aligned} \mathcal{T}^{(0)}_{\rm untw} &\sim |V_4 O_4|^2 + |S_4 S_4|^2 - (O_4 V_4)(\overline{C}_4 \overline{C}_4) - (C_4 C_4)(\overline{O}_4 \overline{V}_4) \,, \\ \mathcal{T}^{(0)}_{fg-{\rm tw}} &\sim 8\, |O_4 S_4 - C_4 O_4|^2 \,, \end{aligned}$$

where we used the level one SO(4) characters O_4, V_4, S_4 and C_4, corresponding to the identity, vector, spinor and conjugate spinor representation. From the above amplitudes we can immediately read off the spectrum which, written in terms of five-dimensional fields, consists in: the metric, 7 Abelian vectors, 6 scalars and 8 fermions from the untwisted sector, and 8 Abelian vectors, 40 scalars and 16 fermions from the fg-twisted sector. The factor 8 in $\mathcal{T}^{(0)}_{fg-{\rm tw}}$ counts the number of fixed points left invariant by the shifts. This partition function has the remarkable property that it is non-supersymmetric, but has the same number of fermionic and bosonic degrees of freedom. Moreover, the torus amplitude is invariant under T-duality and in the limit $R \to \infty$ leads to type IIB on T^4/Z_2 with 21 tensor multiplets coupled to $\mathcal{N} = (2,0)$ supergravity.

Open descendants: The construction of open descendants starts by adding to $\frac{1}{2}\mathcal{T}$ the direct Klein bottle amplitude, which gives at the massless level

$$\mathcal{K}^{(0)} \sim \frac{1}{2}\Big[(V_4 O_4 - S_4 S_4) + \epsilon\,(n_+ - n_-)\,(O_4 S_4 - C_4 O_4)\Big] \,,$$

where $n_+ = 6$ and $n_- = 2$, revealing the fact that the orientifold planes carry different charges under the Ω projection. The two different choices $\epsilon = \pm 1$, which have recently been discussed in [8, 7, 9], give rise to a supersymmetric open string spectrum for $\epsilon = 1$ and a non-supersymmetric open string spectrum for $\epsilon = -1$. The spectrum of massless closed unoriented excitations then results in the following five-dimensional fields: the metric, 2 vectors, 5 scalars and 4 fermions from the untwisted sector and the fg-twisted sector for $\epsilon = 1$ contains 2 vectors, 26 scalars and 8 fermions whereas for $\epsilon = -1$ it comprises 14 scalars, 6 vectors and 8 fermions. For both choices the spectrum has bose-fermi degeneracy. Since the Klein bottle amplitude only feels the left-right symmetric part of the torus amplitude, it is supersymmetric and thus results in a vanishing 1-loop contribution to the cosmological constant.

The open string sector is obtained by adding the direct annulus amplitude to the direct channel Möbius strip. In the following we will concentrate on the choice $\epsilon = 1$. Since the five dimensional theory is invariant under T-duality, the annulus amplitude has to be parameterized by charges, that represent a linear combination of $D9$ and $D5$ branes. For the massless contribution to the direct annulus amplitude, we thus get:

$$\mathcal{A}^{(0)} \sim \frac{1}{4}\Big\{[I_M^2 + R_M^2](V_4O_4 - S_4S_4) + [I_M^2 - R_M^2](O_4V_4 - C_4C_4)\Big\}\,,$$

where I_M denotes the sum of Chan-Paton charges, whereas R_M parameterizes the gauge symmetry breaking, induced by the orbifold action. For the Möbius amplitude one has two options:

$$\mathcal{M}_1^{(0)} \sim \frac{1}{2} I_M(\hat{V}_4\hat{O}_4 - \hat{S}_4\hat{S}_4)\,, \quad \mathcal{M}_2^{(0)} \sim -\frac{1}{2} I_M(\hat{O}_4\hat{V}_4 - \hat{C}_4\hat{C}_4)$$

where for the second Möbius amplitude, we introduced a discrete Wilson line. Inspection of the above Möbius amplitudes requires the gauge group to be symplectic in the first case and unitary in the second. Tadpole conditions give $I_M = 16$ and $R_M = 0$, which can be extracted from the transverse channel amplitudes $\tilde{\mathcal{K}}^{(0)}$, $\tilde{\mathcal{M}}^{(0)}$ and $\tilde{\mathcal{A}}^{(0)}$. This fixes the size of the gauge group. In order to have a consistent particle interpretation of $\mathcal{A}^{(0)} + \mathcal{M}^{(0)}$ we have to choose

$$\begin{aligned} &1.) \quad I_M = M_1 + M_2\,, \quad R_M = M_1 - M_2 \\ &2.) \quad I_M = M + \overline{M}\,, \quad R_M = i(M - \overline{M}) \end{aligned}$$

The resulting spectrum in the first case comprises a vector in the adjoint of $\mathrm{Sp}(8)^{\otimes 2}$ and a hypermultiplet in the bifundamental representation $(8, 8)$ and in the second case a vector in the adjoint of $\mathrm{U}(8)$ and a hypermultiplets in $28 \oplus \overline{28}$.

In the limit $R \to 0$, the amplitudes reveal that new tadpoles arise, due to odd windings that become massless. On the other hand, taking the limit $R \to \infty$ one recovers the two six dimensional models with quantized antisymmetric tensor background [10, 6, 7] and gauge group $\mathrm{Sp}(8)^{\otimes 4}$ with matter in the representations $(8,8,1,1)$, $(8,1,8,1)$, $(1,8,1,8)$, and $(1,1,8,8)$ for the first case and gauge group $\mathrm{U}(8)^{\otimes 2}$ with matter in the representations $(28 \oplus \overline{28}, 1)$, $(1, 28 \oplus \overline{28})$, $(8, \bar{8})$ and $(\bar{8}, 8)$ for the second case.

Acknowledgments

I am grateful to C. Angelantonj and I. Antoniadis for collaboration and interesting discussions. I would also like to thank the Organizers of the Cargèse Summer School. This work was supported in part by EEC TMR contract ERBFMRX-CT96-0090.

References

[1] S. Kachru, J. Kumar and E. Silverstein, Phys. Rev. D59 (1999) 106004
S. Kachru and E. Silverstein, JHEP 9811 (1998) 001; JHEP 9901 (1999) 004.

[2] J.A. Harvey, Phys. Rev. D59 (1999) 26002.

[3] C. Angelantonj, I. Antoniadis and K. Förger, *Non-supersymmetric type I strings with zero vacuum energy*, to appear in Nucl. Phys. B, hep-th/9904092;
C. Angelantonj, *Non-supersymmetric open string vacua*, hep-th/9907054;
C. Angelantonj, these proceedings.

[4] R. Blumenhagen and L. Görlich, Nucl. Phys. B 551 (1999) 601.

[5] M. Bianchi, G. Pradisi and A. Sagnotti, Nucl. Phys. B376 (1992) 365.

[6] Z. Kakushadze, G. Shiu and S.-H. Henry Tye, Phys.Rev. D58 (1998) 086001.

[7] C. Angelantonj, *Comments on open-string orbifolds with a non-vanishing* B_{ab}, hep-th/9908064.

[8] I. Antoniadis, E. Dudas and A. Sagnotti, *Brane Supersymmetry Breaking*, hep-th/9908023.

[9] G. Aldazabal and A. M. Uranga, *Tachyon-free non-supersymmetric type IIB orientifolds via brane-antibrane systems*, hep-th/9908072.

[10] M. Bianchi and A. Sagnotti, Nucl. Phys. B 361 (1991) 519.